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The AAT/PBV protein evaluation system for ruminants
A revision

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CONTENT SIDE

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The AAT/PBV protein evaluation system for ruminants has now been used in Denmark, Norway and Sweden for some years and will soon be introduced in Finland and Iceland as well. The basic concepts with AAT (amino acids absorbed in the small intestine) and PBV (protein balance in the rumen) and the factors to be considered in predicting the AAT and PBV values are maintained, but the continuous development in methods and knowledge has led to changes in methods used to predict the individual factors. The inclusion of these modifications in the different countries has not taken action at the same time, but depends on the time the different countries has introduced the system and on the calendar for major changes in the feed evaluation system. It has the effect that at a given time the system may be slightly different in the different Nordic countries, but we follow the same line in the development. The following is the most important changes that has been made or are going to be made in the system since the system was first presented. In the prediction of the AAT and PBV values of the feeds: 1) changes in the nylon bag procedure to predict the protein degradability in the rumen by correcting for particle loss and for microbial N contamination of the bag residues in fibrous feeds, 2) a change from using a constant figure of 0.82 for intestinal digestibility of undegraded amino acids to an actual determination of the intestinal digestibility of the single feeds, 3) a microbial amino acid synthesis per kg of digested carbohydrates on fresh grass of 135 g is used instead of the general factor of 125 g which is maintained on all other feeds. The recommendations for AAT and PBV to different categories of ruminants will depend on the actual economical situation and feeding system and will therefore differ from place to place and probably from time to time as well. In general, it has been observed that the potential of decreasing the protein allocation is greater than the possibilities of increasing the milk yield or the weight gain, by using the AAT/PBV system instead of the digestible crude protein system.

Key words: Nitrogen, nordic, amino acids, digestibility, feed

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INTRODUCTION

The AAT/PBV protein evaluation system for ruminants was proposed to be used in the Nordic countries by a Nordic working group (NKJ,1985). The basic concepts of the system was defined by Madsen (1982) and Hvelplund (1982) and later discussed in detail by Hvelplund and Madsen (1990). It uses the units AAT (amino acids absorbed in the small intestine) and PBV (protein balance in the rumen). The system is now in use in Denmark, Norway and Sweden, and the basic concepts of using AAT and PBV has not been changed, but there has been a development and change in the methods used to predict the AAT and PBV values of the feeds. These methods to predict the different factors in the AAT/PBV system may, however, vary from one laboratory to another. More knowledge has also been gained about the requirements of different categories of ruminants. The recommendations given for feeding ruminants in the different countries may be different. The present publication is a summary and synthesis of the information published since the system was introduced and a description of the present situation is given together with information on the practical use of the system in the different countries.

CALCULATION OF AAT AND PBV

A direct measurement of the AAT and PBV value of all available feeds using fistulated animals is not realistic. Therefore formulas were developed by which the AAT and PBV were expressed by factors which are either constants, or variables which can be related to analysis on the feeds:

AAT, g /kg DM
= crude protein, g /kg DM
* (1-degradability in the rumen)
* proportion of amino acids in undegraded feed protein
* digestibility in the small intestine of undegraded amino acids
\+ microbial protein produced, g /kg DM
* proportion of amino acids in microbial protein
* digestibility in the small intestine of microbial amino acids

PBV, g /kg DM
= crude protein, g /kg DM
* degradability in the rumen
\- microbial protein produced, g /kg DM

The methods used to determine the individual factors will be referred to and discussed in the following.

Protein degradability

Rumen degradability of feed proteins should be estimated by the nylon bag technique (Ørskov and McDonald, 1979; McDonald, 1981; Lindberg, 1985; NKJ, 1985; Kristensen et al., 1982). It is recommended that the procedure described by Madsen and Hvelplund (1994), and agreed upon by an EEC-EAAP working group, is used as the reference nylon bag procedure. The procedure is summarized in table 1.

As pointed out by Madsen and Hvelplund (1994) the deviations between laboratories in the degradation figures obtained are too big. The nylon bag procedure should be standardized as much as possible to allow exchange of data between countries. At present it is not recommended to use degradation figures from different laboratories for the national feedstuff tables or for direct comparisons.

However, the different laboratories rank the feedstuffs in the same order and comparisons between feedstuffs within laboratories are possible. It is recommended that a standard feed is circulated between laboratories to calibrate the nylon bag procedure and that frequent ring tests are performed.

A problem with the nylon bag method is that for some feeds a substantial part of the non-water soluble material may leave the nylon bag through the pores and are thus estimated as being degraded although the material is lost as small particles. A further problem with the nylon bag method is that soluble peptides washed out of the nylon bag may not be fully degraded as shown by Chen et al. (1987) as they found that the flow of peptides from the rumen to the small intestine may be substantial. The loss from the bags can be substantial, especially in compounded feedstuffs and in starch rich feedstuffs, including whole-crop cereals. The particle loss can be estimated as the difference between washing loss from the bags and true water solubility estimated as the washing loss over filter paper.

The procedure for determining water soluble N is: Duplicate samples of approximately 1 g are weighed into 100 ml centrifuge tubes, 40 ml of tap water is added and it is kept at approximately 20 °C for 1 hour. The material is then transferred to a N-free filter with retention 2 (blue ribbon, Schleicher and Schuell), washed 4 times with 40 ml tap water. The residual N is determined and the water soluble N is calculated as the difference between the original amount of N in the feed sample and the residual amount of N.

Assuming the particle loss is degraded in the same way as the fraction which remains in the bags, corrections can be made for this (Weisbjerg et al., 1990, Madsen and Hvelplund, 1994). The influence of a correction for particle loss on protein degradability in compounded feedstuffs is shown in table 2. From this it is obvious that for some feeds the particle loss can be quite substantial and, consequently, influence the degradability estimated if not taken into consideration. However, the assumption that particle loss is representative can be questioned, especially for compounded feedstuffs containing many different ingredients in which the particle distribution may vary between these ingredients.

Because of a potential high particle loss when finely ground feeds are incubated in nylon bags it is recommended that the measured degradations of concentrate mixtures and other finely ground feeds are corrected for the particle loss from the nylon bags according to formula 1.

Microbial contamination of the residues left in the bags after rumen incubation can also be substantial, especially for roughage low in protein, whereas it is of minor importance for concentrates (Lindberg, 1985, Varvikko & Lindberg, 1985). To reduce the problem of contamination of residues in the bags a stomacher can be used after incubation. Use of the stomacher method to remove adhering bacteria was tested in a study using N^{15} (Hvelplund & Lindberg, unpublished). The study showed that the normal procedure using only machine washing generally underestimated the protein degradation, and the underestimation increased with decreasing protein level in the feed. Use of stomacher resulted in an overestimation of protein degradation in feeds like whole-crop cereals and an underestimation in feeds like straw and grass. Therefore, this method is not perfect, but stomaching was clearly superior to no treatment. This is in agreement with French results which

Table 1.Recommended standard nylon bag procedure for determining protein degradability in the rumen

Parameter	Recommendation
Bag pore size	37 my
Sample size to bag surface ratio	10-15 mg/cm^2
Sample preparation	Freeze-drying of wet samples. Grinding through a 1.5 mm screen
Animal and feeding	Three non-lactating dairy cows fed at maintenance level on a diet consisting of hay and concentrate mixture at the ratio of 2:1. The concentrate mixture should contain approx. 17.5% crude protein on dry matter basis
Incubation intervals:	
- all feeds	0(washing only) 2,4,8,16,24 and 48 h.
- roughage and slowly degradable protein sources	+ 72 h
- straw	+ 72 h and 96 h
Washing of bags	Domestic washing machine for 3 x 10 min. with cold water.
Calculations	Effective protein degradability (EPD) according to Ørskov & McDonald (1979) or Kristensen et al. (1982) with outflow rate (k) of 5% h^{-1}. Correction for washing loss of nitrogen from the nylon bags according to the procedure given below

Table 2. Water-soluble nitrogen, washing loss of nitrogen from bags, and effective degradation of protein (EPD) calculated at an outflow rate of 0.05 h^{-1}, uncorrected and corrected for loss of nitrogen, respectively, for different concentrate mixtures

Mixture	*Water-soluble N* %	*Loss of N from nylon bags after washing* %	*EPD uncorrected* %	*EPD* corrected* %
1	6.3	41.9	72.7	56.0
2	14.9	35.7	74.7	66.5
3	16.4	47.3	81.1	70.0
4	8.1	35.1	66.1	51.9
5	10.4	33.3	74.1	65.2

**Corrected using equation 1*

$EPD_{corr} = A + [(100 - A)/(100 - B)] \ (C - B)$ *(1)*

A = *Water soluble N, %*

B = *Loss of nitrogen from the nylon bag after washing, %*

C = *Uncorrected EPD, %*

showed that stomaching was superior to chilling and sonication for removal of bacteria adhering to roughage residues in nylon bags (Michalet-Doreau & Ould-Bah, 1992). It is recommended that all roughage samples are corrected for microbial contamination before calculating EPD.

The effective feed protein degradability (EPD) can be calculated either according to Ørskov & McDonald (1979) or according to Kristensen et al. (1982). Theoretically, the rumen outflow rate of undegraded feed protein is lower than 0.05-0.08 h^{-1}, which is used in the system and which is determined using external markers like Cr mordanted straw. These markers represent more or less the indigestible neutral detergent fibre (NDF) (Tamminga et al. 1989; Huhtanen & Khalili 1991), and flow rate of undegraded dietary protein is close to that of NDF. Using rumen evacuation technique, Tamminga et al. (1989) calculated values between 0.016 and 0.217 h^{-1} for passage rate of digestible NDF in two experiments with dairy cows. Further, incorporation of residence time in a two-compartment model will decrease the passage rate (Huhtanen et al. 1993). Using too high outflow rate will result in a lower digestibility and protein degradation in the rumen. Initially, an outflow rate of 0.05 h^{-1} was suggested by NKJ (1985). In Denmark an outflow rate of 0.08 was used when the system was introduced in 1989 (Hvelplund & Madsen, 1990), but 0.05 h^{-1} is used now. This change in passage rate has been made without major changes in the degradability values as, at the same time, the feeding of the cows in which the bags are incubated was changed from only hay to a ration of both hay and concentrate and it is now recommended to correct the figures for particle loss from the nylon bag. It has been shown that feed samples incubated in a cow fed a hay: concentrate diet (50:50 on a DM basis) and calculating of EPD with k = 0.05, gave estimates comparable with those obtained in hay-fed cow when EPD was calculated with k = 0.08 (Thøgersen, 1986). This was also indicated by Lindberg (1985) when comparing the nylon bag procedures used in the different Nordic countries.

In Finland different outflow rates of protein is used for different feeds as follows: Roughage = 0.02 h^{-1}, grain = 0.03 h^{-1}, protein concentrates = 0.04 h^{-1}.

In Sweden a passage rate of 0.08 h^{-1} is used and no correction is made for particle loss from the nylon bags nor is a stomacher correction made to correct for microbial contamination of bag residues from roughages. A constant value for EPD of 80% is used for all grass silages and hays. For straw a standard value of 60% is used

The variation in EPD value, within some feedstuffs, can be estimated from buffer-solubility measurements (Madsen & Hvelplund, 1985; Lindberg, 1986). An enzymatic in vitro method (Aufrere & Cartailler, 1988) using a protease extracted from streptomyces griseus has shown promising results and is used in France (Aufrere et al., 1991). Results obtained with this method in Norway also show promising results for most protein rich concentrates, but more variable results for concentrate mixtures, especially those containing a high proportion of barley or oats (Hiob et al., 1992; Vognsen et al., 1994; Vognsen & Harstad, unpublished). Michalet-Doreau & Ould-Bah (1992) concluded that enzymatic methods may be more suitable for measuring relative differences between feedstuffs than for providing absolute degradation values. Further research in this field is therefore recommended.

Amino acid content of undegraded dietary protein

The amino acid content in undegraded dietary protein has been estimated in residues from the nylon bag incubated in the rumen at different hours of incubation (Ganev et al, 1979; Hennessy et al, 1983; Varvikko et al, 1983; Hvelplund & Hesselholt, 1987; Rooke et al, 1984; Hvelplund, 1987; Erasmus et al., 1994). Although there are deviations, the main conclusion from results on concentrate feeds is that the proportion of amino acids in the undegraded residue is of the same order as found in the original protein. The amino acid proportion in undegraded protein from roughage seems to be lower compared to the amino acid proportion in the original protein.

A consequence of these findings could be that the proportion of amino acids in undegraded feed protein from concentrates was fixed to the value found in the original feed and for roughage a reduction in the undegraded protein compared to the original protein of approximately 20 % units. For the system we have chosen a proportion of amino acids in the undegraded protein from concentrate of 0.85 and for roughage of 0.65. Compared to other protein evaluation systems proposed during the last decade these values are low. A factor of 1.0 for the proportion of amino acids in the undegraded protein is used in most of the other systems. Justification for the factors used in the AAT-PBV system can be found in published results on the proportion of amino acids in the duodenal content. This has been discussed in some detail by Hvelplund (1986 & 1987), and the conclusion was that the factors used was in agreement with actual flow measurements. A change from a fixed factor of 0.85 for concentrates and 0.65 for roughage to the actual proportion in the different feeds with a reduction factor for roughage would be complicated compared to the present system. It is therefore recommended based on present knowledge that we do not change the evaluation of amino acid content in undegraded dietary protein, but that research continues on this issue, which eventually will lead to different figures on different feeds, especially reduce the values on some roughage.

Digestibility of amino acids in undegraded dietary protein

A factor of 0.82 was proposed for the digestibility of amino acids in the undegraded dietary protein when the AAT-PBV system was first introduced. It was also realized that the digestibility of amino acids in undegraded dietary protein may vary and especially in situations where the protein is protected against degradation in the rumen. The possibility exists that the digestibility may be reduced quite substantially (Hvelplund, 1985). The mobile nylon bag technique has been described as a reliable, easy and cheap tool to test the digestibility of undegraded dietary protein in ruminants (Todorov and Girginov,1991; Jarosz et al.1991; Hvelplund et al.1994). On the other hand, recent results with ryegrass and rapeseed meal do not confirm the correspondence between values obtained by the mobile bag method and those obtained in vivo with ^{15}N technique (Varvikko and Vanhatalo 1990; Vanhatalo and Varvikko, unpublished). However, the method has shown consistency in relative ranking of feeds. The recommended procedure is described in table 3.

Work with this method has revealed that there are big differences in the digestibility of undegraded dietary protein among different protein sources (Hvelplund, 1985; Volden and Harstad, 1994). Further work with this method also

showed that there were differences in digestibility of the undegraded dietary protein within the same protein source. An increased degradability of the protein leads to a reduced digestibility of the undegraded protein and these observations lead to formulation of the following equation.

$$TD = (UDN-TU)/UDN \quad (2)$$

TD = true digestibility of rumen undegraded dietary protein in the small intestine

UDN =fraction of undegraded dietary nitrogen

TU = fraction of true indigestible nitrogen in the feed.

The validity of this equation has been tested on a number of feeds and the results indicate that the digestibility of undegraded dietary protein on several feeds can be calculated according to this formula (Hvelplund et al. 1992). This means that the information necessary to calculate the true digestibility in the small intestine at any rate of degradation is the true digestibility of the protein in the original feed and the actual degradation.

The true digestibility of the original protein and of the undegraded protein at different degradabilities estimated with the mobile nylon bag technique is shown for rapeseed meal and grass silage in figure 1.

Table 3. Recommended standard mobile nylon bag procedure for determining intestinal digestibility of rumen undegraded protein

Parameter	Recommendation
Bag pore size	11 µm
Bag surface area	6 x 6 cm
Samples	Original feed or residues of rumen undegraded material
Sample size	Concentrates 10-15 mg per cm^2 = approx. 1 g Roughage: 5-7 mg per cm^2 = approx. 0.5 g
Animals and feeding	These duodenal fistulated cows fed according to production
Replications	Two replicates per cow
Preincubation	Step 1. In 0.004 M HCl solution at pH = 2.4 for 1 hr Step 2. In a pepsin/HCl solution (100 mg pepsin per liter of 0.004 M HCl solution, pH = 2.4) for 2 hrs at 40°C in a shaking water bath
Washing of bags	Rinse with tap water and subsequently wash in a sieve basket in cold running water for two hrs
Calculations	According to Hvelplund et al. (1992). See Eq. 2

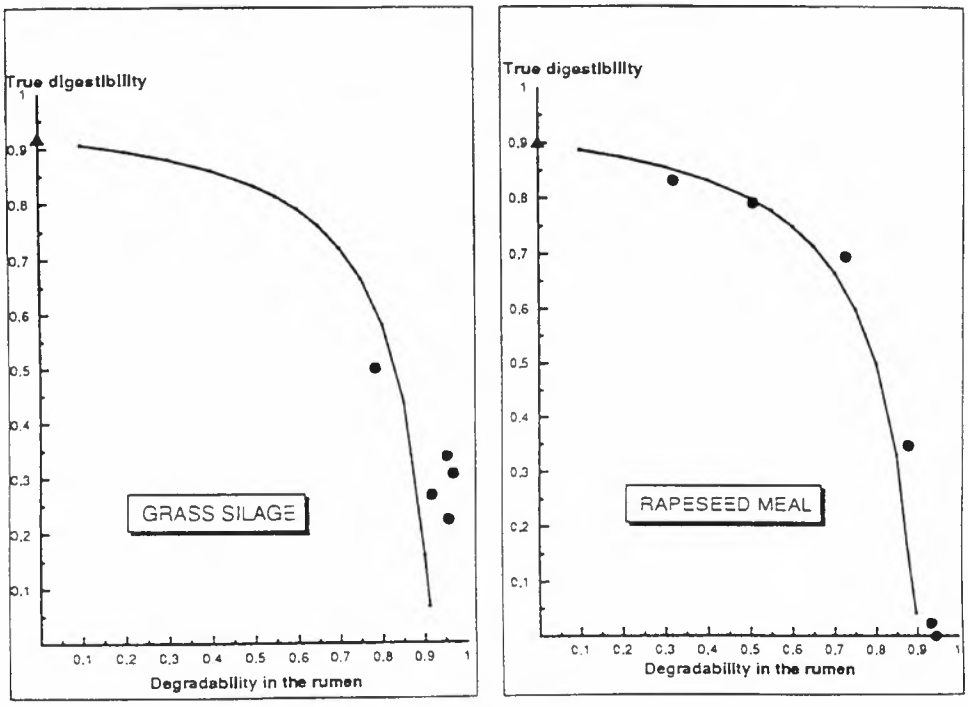

Figure 1. Disappearence from the mobile nylon bag (true digestibility) of undegraded N from rapeseed meal and grass silage at different degradabilities of the N i the rumen (Hvelplund et al., 1992)

The consequences of using this equation for rapeseed meal, with a degradability of the protein in the rumen of 0.68. would be a digestibility of the undegraded protein of 0.69 instead of 0.82 as previous used in the system. For grass silage with a degradability of the protein in the rumen of 0.85 the consequence would be a digestibility of the undegraded protein of 0.47 which is far from the value used in the system.

The consequences of using the above equation to calculate the true intestinal digestibility and the resulting AAT and PBV values in different feeds is shown in table 4.

As expected, and often stressed, the factor of 0.82 cannot be used if a protein is overprotected. This is quite obvious from the example shown for soybean meal in table 4. For normal feeds where no treatment has been applied the differences between the values calculated with the average digestibility of 0.82 and the value found if the equation was applied are still substantial for some feeds. For concentrate the consequence of changing to the formula will be both increases and decreases in the AAT value of the undegraded dietary protein, whereas for roughage it means a decrease because all roughage have a high degradability of protein in the rumen.

For many diets where the concentrate is composed of ingredients with both positive and negative changes in the AAT value a shift from a fixed factor of 0.82 to a variable factor according to the equa-

Table 4. AAT and PBV values of some feeds using the original intestinal digestibility of 0.82 or the digestibility obtained by formula 2

Protein source	CP g/kg	EPD	True intestinal dig. of original protein*	True digestibility coefficent		AAT undegrades		Difference
				System	Equation**	System	Equation	AATsyst. -ATTeq.
Soybean meal	515	0.60	0.96	0.82	0.90	110	121	-11
Cottonseed meal	482	0.56	0.94	0.82	0.86	148	155	-7
Rapeseed meal	395	0.68	0.90	0.82	0.69	88	74	14
Coconut meal	237	0.37	0.93	0.82	0.89	104	113	-9
Peas	242	0.77	0.92	0.82	0.65	39	31	8
Soybean meal,[a]	515	0.35	0.96	0.82	0.94	233	267	-34
Soybean meal, [b]	515	0.25	0.48	0.82	0.31	269	102	167
Grass silage	162	0.85	0.92	0.82	0.47	13	7	6
Barley whole crop silage	127	0.74	0.88	0.82	0.54	18	12	6
Maize whole crop silage	104	0.62	0.87	0.82	0.66	21	17	4
Ryegrass, early cut	301	0.82	0.95	0.82	0.72	29	25	4
Ryegrass	113	0.69	0.89	0.82	0.65	19	15	4

**) estimated by mobile nylon bag technique, **) TD = (UDN-TU/UDN)*
[a] protected, [b] overprotected

tion will only have a marginal influence on the AAT content of the diet. However, in some diets it may have a substantial effect and based on available evidence the equation seems to predict the correct digestibility. The principle has therefore been introduced for calculation of the digestibility of amino acids in undegraded dietary protein. In doing this, it is assumed that the digestibility of protein and amino acids is identical. This is probably not always true as shown for four roughages (Skorko-Sajko et al.1994) where the digestibility of amino acids was higher than for crude protein in both the original protein and in residues which had been preincubated in the rumen for 16 hrs. Further research is necessary on a wide range of feeds to solve this important issue.

Work with tropical forages has however shown that the validity of equation 2 is not general (Mgheni et al.1994). The hypothesis behind the equation that a feed contains a protein fraction which is both undegradable in the rumen and indigestible in the intestine was not found valid as preincubation in the rumen increased the availability of the protein in these feeds. For temperate feeds the hypothesis seems valid on several feeds (Hvelplund et al.,1992; Van Straalen et al.,1993). However, investigations in Norway indicate that the validity of equation 2 do not hold for all temperate feeds either (Volden and Harstad, 1994). It is recommended that the digestibility of undegraded dietary protein for those feeds is calculated on basis of true indigestible N fraction (TU) determined after 16 and 24 h in the rumen for concentrate and roughage, respectively.

In Sweden the original factor of 0.82 is used as a standard figure for all feeds except a few well-known feeds with exceptionally low digestibility. In order to avoid overestimated AAT values of feeds processed for low EPD values, the processed feed has to prove an unaffected digestibility in the small intestine before the lower EPD value is accepted.

The true digestibility of the original protein can be obtained with either the mobile nylon bag technique or by in vitro methods. The mobile nylon bag requires intestinal cannulated animals and this method is therefore not suited as a routine method and work is therefore in progress with enzymatic methods which can be used to predict digestibility of the original protein which also enables routine check on this important parameter.

Microbial protein synthesis

Although the variability of the estimated microbial synthesis is reduced by expressing the efficiency in relation to digested carbohydrates rather than digested organic matter which is used in some other systems, there are still a great variability in the estimates of microbial synthesis in the rumen.

Although some of the differences may be ascribed to technical problems there seems to be differences according to the diet fed. The reason for this variation can be ascribed to a number of factors. Besides energy, specific nutrients from the feed can be a limiting factor for microbial growth in the rumen. An adequate supply of nitrogen either from degradable protein or from recycled nitrogen is essential for optimal microbial growth and although ammonia-nitrogen can serve as the principal nitrogen source for microbial protein synthesis this synthesis may well be influenced by the "quality" of the degraded protein (Thomsen, 1985; McAllan et al., 1988; Ciszuk & Lindberg, 1988). The protein quality aspect for the rumen microbes is considered only to be of major importance when straw is constituting a major portion of the ration as it can do

for heifers, suckler cows and ruminant livestock in the third world.

Other factors have been mentioned as responsible for this variability, such as digesta passage rate from the rumen, recycling of bacterial nitrogen in the rumen due to lysis and protozoal predation of bacteria and limitation of specific nutrients in the rumen. To what extent these factors have been responsible for the variability found in the efficiency of microbial protein synthesis when related to total digestible carbohydrates cannot at present be deduced from these experiments. A factor for the microbial amino acid nitrogen synthesis per kg of totally digested carbohydrates of 20 g was chosen in the system (Madsen, 1985). This value was close to the value found in experiments with sheep in Norway by Harstad & Vik Mo (1985). Other experiments with the aim to test if the microbial production is 20 g amino acid nitrogen per kg digestible carbohydrates have been conducted by Møller (1985) and Hvelplund & Madsen (1986). In these experiments the microbial synthesis was found to be 10 % and 20 % higher than the value chosen for the system. Values in the same order are also obtained with dairy cows at high feeding level in Norway (Kjos, 1992; Harstad and Volden, unpublished). The efficiency of microbial synthesis in these experiments was related to the amount of carbohydrates digested at production level, whereas when the synthesis is calculated according to the system this is based on the digestion of carbohydrates estimated in digestibility experiments with sheep fed at maintenance. In the latter case the digestion of carbohydrates is higher than the digestion found when estimated at production level. An analysis of the Danish experiments (Madsen, 1988) gave the results shown in equation 3.

The measured flow of amino acids to the duodenum was multiplied with factors for amino acid digestibility in the small intestine to get a value of AAT measured and these values were compared with the values which could be calculated based on actual figures from protein degradability and digested carbohydrates estimated in digestibility experiments with sheep using the proposed system (Madsen, 1985).

All these experiments were conducted at a high feeding level. The 5 % higher value is probably related to a high passage rate in these experiments. In the range of 7 to 14 kg dry matter intake per day there were no changes in the protein value of different feeds (Madsen, 1986). As the system cannot cover all situations it seems reasonable to stick to the original factor of 125 g amino acid or 20 g amino acid nitrogen synthesized per kg totally digested carbohydrates until more quantitative knowledge is gained about variability in microbial synthesis in the rumen. Values for fresh grass as given in the feedstuffs tables in Denmark, Norway and Sweden (Strudsholm et al.,1993; STIL, 1993; Spörndly, 1993) are however based on a microbial synthesis of 135 g amino acids per kg digested carbohydrates. This value is not experimentally justified but based on the practical experience that cows can produce well on rations based on fresh grass even if the AAT supply calculated on the basis of 125 g amino acids per kg digested carbohydrates, do not meet the theoretical AAT requirement.

Improvements in the prediction of the microbial protein synthesis can be expected in the future by inclusion of knowledge as: Fermentation of feed protein provides half of the ATP produced by fermentation of carbohydrates (Demeyer and Van Nevel, 1979), some rumen

$$AAT_{measured} = 1.05 \times AAT \text{ system} \quad (3)$$
where: Mean $AAT_{measured}$ = 1630 g/day, sd = 83, CV = 5.1 %, n = 20

bacteria utilize peptides as N source (Russel et al., 1991), and that end products of silage fermentation does not form the basis for microbial protein synthesis in the rumen even if it is included in the nitrogen free extract (NFE) fraction and in that way in the amount of digestible carbohydrates. Some protein evaluation systems have recently changed the way of expressing the microbial protein synthesis and relate the synthesis to the amount of fermentable organic matter in the rumen (PDI, France; MP, England; DVE, Netherlands). In Germany Voigt and Piatkowski (1991) based their calculations of microbial synthesis on the apparently digested organic matter corrected for undegraded protein.

Data from several milk production experiments on grass silage based diets was recalculated by Tuori (1992). The results from this analysis indicated that adding degradable protein to the digestible carbohydrate fraction of the feed in estimating microbial protein synthesis in combination with a reduction of the rumen outflow rate of undegraded protein resulted in lower variation coefficient at AAT utilization compared to the present AAT-PBV system. In Finland the microbial protein synthesis is calculated as 179 g microbial crude protein per kg (digestible crude carbohydrates + degradable protein).

Digestible carbohydrates

The amount of digestible carbohydrates in single feedstuffs is derived from the sum of digestible crude fibre (CF) and NFE. The reference values for each feed are obtained through the Weende analysis and determination of digestibility coefficients in sheep fed at maintenance. Indirect estimates of digestible carbohydrates in roughage are possible using the in vitro method to predict the amount of digestible organic matter and from that subtract the amount of digested protein and digested fat. The amount of digested protein and digested fat can be calculated from the total content of protein and fat by the formulas given by Weisbjerg and Hvelplund (1993). An enzyme method can be used to predict the content of digested organic matter in concentrates and the same calculations can be made as for roughage (Weisbjerg and Hvelplund, 1993).

In Sweden the digestible carbohydrates in grass silage and hays are estimated by a regression based on the protein content and the organic matter digested in rumen liquor (Lindberg, 1989). For all other feeds the total digestible carbohydrates are estimated from a Weende analysis and tabulated digestibility coefficients.

Amino acid content of rumen microbes

Based on 49 bacterial samples isolated on a variety of different diets Hvelplund (1986) found a variation between 0.62 and 0.72 for the proportion of amino acid nitrogen in total bacterial nitrogen. These values are much lower than the average value of 0.83 reported by Storm (1982) based on a literature survey. The reason for this discrepancy is at present not clear, but could possibly be ascribed to both nutritional and analytical factors. However, if the proportion of amino acid nitrogen

in duodenal non-ammonia nitrogen obtained from published results on a variety of different diets are compared to values obtained for undegraded dietary protein and microbial protein a factor of 0.70 for microbial protein seems justified as discussed by Hvelplund (1986). A factor of 0.70 for the proportion of amino acid nitrogen in total bacterial nitrogen is therefore still recommended.

Intestinal digestibility of microbial amino acids

Estimates of the true digestibility in the small intestine of amino acids in bacterial protein has been obtained by Tas et al.(1981), Storm et al.(1983) and Hvelplund (1985). The values obtained in these studies varied between 0.85 and 0.87, which indicates that the true digestibility of amino acids in bacterial protein can be considered as a constant and a value of 0.85 is still recommended in the AAT-PBV system.

AAT-PBV VALUES OF FEEDS

An example of calculation of the AAT and PBV values for soyabean meal is shown on top of page 18.

A feedstuff table including the AAT and PBV values of the feeds used in Denmark and the methods used to calculate the feed values is published periodically. The 1993 version is Report no. 28 from the National Committee on Danish Cattle Husbandry (Strudsholm et al. 1993). Similar a database on the present recommendations for feeding, including AAT and PBV, has been published (Strudsholm et al. 1992). The AAT values of several of the feeds, especially the roughages, have decreased after introduction of the stomacher method in the determination of the protein degradability as well as the new principle for calculation of digestibility of undegraded dietary protein. In Norway, a feedstuffs table with AAT and PBV values was published in 1992 (STIL, 1992). A revision is planned to be published in 1995. In Sweden, official AAT/PBV-values of feeds and feeding recommendations was first published in 1989. Revision of the official feed table from the Agricultural University were made in 1991 and 1993 (Spröndly, 1993).

BASIS FOR AAT AND PBV RECOMMENDATIONS

Basically the recommendations for AAT and PBV in different situations have to be based on production experiments, where marginal outputs are related to the input of AAT and PBV. Such experiments are expensive and time-consuming, and many experiments are required. Therefore, a first and valuable approach is to use the information which can be gained by looking at the net requirements of amino acids for different productions and for maintenance.

Recommendations for AAT

The question arises how requirements should best be expressed. Several possibilities exist:

1. g /kg feed dry matter
2. g /energy unit (net energy or metabolizable energy)
3. g /unit energy for production and maintenance separately.
4. g /day
5. g /kg ECM, kg weight gain and for maintenance
6. g /g protein in milk, in weight gain and need for maintenance

Crude protein in dry matter	51.6 %
Nylon bag degradability of the protein	64 %
Proportion of undegraded amino acids in undegraded protein	85 %
Digestibility of undegraded amino acids	90 %
Digested carbohydrates(NFE + crude fibre)	350 g
Proportion of amino acids in microbial protein	70 %
Digestibility of microbial amino acids	85 %

AAT= 516 * (1-0.64) * 0.85 * 0.90 + 0.02 * 6.25 * 350 * 0.85 = 179.3 g per kg dry matter

PBV= 516 * 0.64 - 0.02 * 6.25/0.7 * 350 = 267.7 g per kg dry matter.

The last mentioned possibility seems to be the most logical way of expressing the AAT requirement. Expressed in this way, the ratio between the net and the gross requirement is equal to the utilization of the protein for the production in question.

Examples of estimated net requirements of protein for different productions and maintenance is shown in table 5.

The utilization of the protein will vary according to the type of production and feeding regime, and it should be stressed that the maximum utilization is almost certainly not the most profitable, as the production at that point will be limited by shortage of amino acids.

These considerations illustrate the difficulties which can arise in comparison of experiments, even when the same and most obvious expression of the protein requirements is used. The situation becomes even more complex when the AAT requirement is expressed per kg of 4% FCM produced or per unit of feed consumed.

Recommendations for PBV

Some possible ways of expressing the optimum level of PBV or the minimum level, which is equal to the maximal level of recycling of crude protein, may be:

1. As a percentage of the crude protein intake
2. g / day
3. g / energy unit

The maximum recycling is not likely to support optimum production, as the microbial fermentation and thereby the digestibility of the feed may be suboptimal.

Preliminary recommendations for dairy cows.

The preliminary AAT and PBV requirements for dairy cows (Madsen, 1985), were partly based on recalculation of earlier production experiments using mean values for AAT and PBV content of the individual feeds. They are shown in table 6.

PROTEIN RECOMMENDATIONS IN THE NORDIC COUNTRIES

DENMARK:

Dairy cows:

To simplify the complexity of establishing recommendations for AAT to dairy cows it is possible to look at the first part and the latter part of the lactation separately,

Table 5. Estimated net requirements of protein for maintenance and different productions

Type of production			Net requirement in g protein pr kg	
4% FCM:	RDM(Red Dave)		33.8)	
-	SDM (Friesian)		32.9)	LK (1989)
-	Jersey		29.4)	
Pure muscles:			200	
Weight gain:	SDM bulls:	200 kg	140)	
-	-	400 -	126)	ARC (1980)
-	-	600 -	125)	
-	Dairy cows		75)	
Weight loss	-		56)	

Net maintenance requirement of tissue protein:
g/day = weight in $kg^{.75}$ * 2.2 ARC (1984)

as they represent different feeding principles, due to the different physiological state of the cow.

1. The feeding system recommended in Denmark is to allocate a constant amount of concentrates to all cows in the first 4 to 8 months of the lactation, and to feed roughage ad libitum (Østergaard, 1979) or to feed a complete diet to the cows in this period.

2. When the first period with constant feeding has finished, the cows are fed according to requirements for the milk produced and the desired weight gain.

What has to be established in relation to AAT requirements to dairy cows is the response to increased AAT supply in the beginning of the lactation.

In the later part of the lactation the rumen microbes synthesize protein in excess of the requirement of the cows. Consequently there is no need to find the exact amount of amino acids required when the cows are gaining weight.

Production experiments in Denmark to establish requirements for dairy cows (Kristensen et al.,1985; Hvelplund et al.,1987; Kristensen et al.,1988; Aaes et al.,1991) has led to the following:

The recommended AAT supply to dairy cows in the beginning of the lactation was, based on several production experiments in Denmark, established to be 97 g AAT per total Scandinavian Feed Unit (SFU) allocated. These production experiments has been recalculated after the revision of the AAT and PBV values of the feed and will in the future be 90 g AAT/SFU. The recommended PBV allocation is 0 PBV in the beginning of the lactation. Cows later in lactation and in the dry period are fed according to their requirements for maintenance, milk and weight gain.

The AAT requirements in table 7 are lower than the originally proposed requirements and 7-8% lower than the requirements given before the revision of the AAT and PBV values in 1994.

Table 6. Preliminary AAT and PBV recommendations

AAT		
	Maintenance:	3.3* weight $^{0.75}$ g AAT
	Milk:	45 g AAT /kg 4% milk
PBV		
	Maintenance	min. -400 g PBV/day
	Maintenance & milk	min. -200 g PBV/day

Table 7. Danish AAT and PBV recommendations for dairy cows

AAT:	
Beginning of lactation	90 g/SFU
Later in lactation	
25 kg EMC	89 g/SFU
15 kg EMC	84 g/SFU
Maintenance	81 g/SFU

If the feeding later in lactation and dry period follows the energy norms then the following can be established:

Maintenance:		3.00 * weight in kg $^{0.75}$ g/day	
Milk:		37 g/kg ECM	
		g AAT per day	
Pregnancy:		Big breeds	Jersey
Month	7	55	35
-	8	95	55
-	9	160	95
Last 14 days		215	130

These figures has to be corrected for the energy utilization obtained. If the energy utilization eg. is 92% in mid lactation, then the recommended feeding is:

Maintenance:	3.25 * weight in kg $^{0.75}$ g/day
Milk:	40 g/kg ECM

PBV:		
Beginning of lactation	min. 0	max. 50 g/SFE
Later in lactation	min. 0 to -40 g/SFE	max. 50 g/SFE
Dry cows	min. -40 g/SFE	max. 50 g/SFE

Growing cattle:

For growing cattle the main conclusions from the Danish production experiments are given by Andersen & Foldager (1988) and Andersen et al. (1994). According to these authors the following can be concluded at present:

1. Compared to dairy cows in early lactation the AAT requirement per SFU of

growing cattle of the dual purpose breeds is relatively low, and in most situations the synthesis of microbial protein covers more than the requirement of AAT. This means that the PBV value becomes more important than the AAT value for most growing animals. It is likely that the AAT requirement of young bulls with a high growth potential is higher than the amount normally synthesized by the microbes, but it has not been possible to establish the precise size of the AAT requirement for these animals.

2. When growing animals are supplied with excess AAT compared with the amount required they can recycle more nitrogen. Expressing the requirement in PBV only is of less value than to use simply the content of digestible crude protein, as a relatively great proportion of the protein not degraded in the rumen but absorbed as amino acids can be recycled and thus substitute a lack of PBV. At present, where the precise relation between AAT and PBV requirements has not yet been established, the system is not considered to be an advantage for use in feed planning for young stock under practical feeding conditions.

The experiments conducted by Andersen & Foldager (1988) showed that the PBV in the rations for growing young bulls heavier than 200 kg fed concentrated rations according to the Danish standards for energy and protein, will have a PBV/SFU value of approximately -40 g. The heifers fed according to Danish standards will reach a PBV/SFU value as low as -70 g. This very low value is considered to be too low and the protein recommendations for older heifers will be revised on basis of this (Andersen & Foldager, 1988).

Goats and sheep:
No recommendations

NORWAY:

Dairy cows and goats:
Maintenance
The requirements of AAT for maintenance (AAT_m) are adopted from the French PDI system (INRA, 1989) (Equation 4).

$$AAT_m, \text{ g/day} = 3.25 \times W^{0.75} \qquad (4)$$

where:
W = Weight, kg

Lactation
The feeding system recommended for dairy cows and goats in Norway is ad libitum feeding of roughage and supplementation with concentrate according to requirements. Production experiments to establish requirements for milk production are presented by Volden et al. (1992). In brief, the requirements of AAT for lactation (AAT_l) are calculated according to Equations 5 and 6.

$$AAT_{l,cows}, \text{ g /kg ECM} = (40 \times ECM + 0.2 \times ECM^2)/ECM \qquad (5)$$

$$AAT_{l,goats}, \text{ g /kg ECM} = (40 \times ECM + 2.0 \times ECM^2)/ECM \qquad (6)$$

where:
ECM = Energy corrected milk, kg

On the basis of the above equations, the AAT requirements can be expressed in different ways (Equations 7 to 12):

The AAT requirements expressed per day, FEm and kg ECM for a dairy cow and a goat, weighing 550 and 50 kg respectively, are shown in table 8.

Pregnancy
The AAT requirements for pregnancy are based on French recommendations (INRA, 1989) as shown in table 9.

Dairy cows:

AAT_l, g/day $= 40 \times ECM + 0.2 \times ECM^2$ (7)

AAT_{m+l}, g/day $= 87.3\ FEm_m + 40 \times ECM + 0.2 \times ECM^2$ (8)

AAT, g/FEm $= AAT_{m+l} / FEm_{m+l}$ (9)

Dairy goats:

AAT_l, g/day $= 40 \times ECM + 2.0 \times ECM^2$ (10)

AAT_{m+l}, g/day $= 87.3\ FEm_m + 40 \times ECM + 2.0 \times ECM^2$ (11)

AAT, g/FEm $= AAT_{m+l} / FEm_{m+l}$ (12)

where:

FEm = Feed unit milk according to Sundstøl & Ekern (1992)
FEm_m = FEm for maintenance
FEm_l = FEm for lactation,

Table 8. Norwegian AAT requirements for milk production expressed per day, FEm and kg ECM

ECM, kg/day		AAT, g/day (1)		AAT, g/FEm (2)		AAT, g/kg
Cows	Goats	Cows	Goats	Cows	Goats	EKM (3)
10	1	420	42	86	90	42
20	2	880	88	90	94	44
30	3	1380	138	94	96	46
40	4	1920	192	97	98	48
50	5	2500	250	100	100	50

(1) Equations 7 (cows) and 10 (goats)
(2) Equations 9 (cows) and 12 (goats)
(3) Equations 5 (cows) and 6 (goats)

Table 9. Norwegian AAT requirements for pregnancy, g per day

Pregnancy month		AAT requirement	
Cows	Goats	Cows	Goats
7th		100	
8th	4th	160	20
9th	5th	230	40

Table 10. Norwegian recommendations for lower limit for PBV expressed in grams per day

	Dairy cows	Dairy goats
First 4 month of lactation	0	0
Later in lactation and in dry period	-300	-30

Growing cattle:
Maintenance requirement as for dairy cows and goats (Equation 4). A summary of the recommendations of AAT for growing cattle (Havrevoll et al. 1992) is given in table 11.

Sheep
The protein requirements for sheep are presented by Havrevoll et al. (1992). A summary is given below.

Maintenance

$$AAT_{m, incl. wool prod.}, g/day = 2.62 \times W^{0.75} \quad (13)$$

where:
W = weight, kg

Growth
The AAT requirement requirement for growth is 220 g /kg weight gain.

Lactation
Recommended AAT allowances for milk production are shown in table 12.

Pregnancy
The recommendations of AAT allocations for pregnancy are from 20 increasing to 60 g per day during the last 6 weeks of pregnancy.

Protein balance in the rumen
Recommended lower limits for PBV expressed in grams per day are:

Maintenance feeding level:
-15 (40 kg LW) to -30 (100 kg LW)

Lactation 0

Table 11. Norwegian recommendations of AAT and PBV for growing Norwegian Red Cattle, g/day

Live weight	Weight gain	Bulls		Heifers	
kg	g/day	AAT, g	PBV, g	AAT, g	PBV, g
100	400			200	
	600	250	-35	242	-30
	800	295		285	
	1000	335			
150	400			243	
	600	285	-40	286	-40
	800	330		329	
	1000	370		372	
200	400			282	
	600	325	-50	329	-50
	800	370		373	
	1000	415		412	
	1200	455			
300	400			355	
	600	400	-125	404	-100
	800	445		446	
	1000	485		483	
	1200	530			
	1400	570			
400	400			428	
	600	470	-200	479	-150
	800	515		518	
	1000	555		548	
	1200	590			
	1400	625			
500	400			505	
	600	545	-250	553	-250
	800	585		583	
	1000	625		595	
	1200	660			
600	600	630	-250		
	800	660			

Table 12. Norwegian AAT requirements for lactation according to litter size and average daily weight gain of the litters, g/day

Number of lambs	Gain, g/day/lamb	AAT
1	400	120
2	300	185
3	250	250

SWEDEN

Dairy cows

The Swedish recommendations are mainly based on experiments performed at the university's research station in the late 1980's and early 90's (Bertilsson, 1990; Bertilsson et al., 1994) Figures from 14 treatment groups with more than 150 lactations (both primi- and multiparous) were considered. The ultimate aim of these experiments was to obtain input-output relationships between feeds evaluated according to the AAT/PBV system and milk production expressed in various ways.

The experiments were carried out in early and mid-lactation. Overall means and range for treatment groups were: milk (kg/cow/day) 27.8, 24.9-32.4; ECM (kg/cow/day 29.3, 25.0-35.0; live weight (kg) 594, 555-628.

The experimental rations were typical Swedish, based on grass silage and/or hay plus grain (barley/oats) and beet pulp. Protein supplements included were: rapeseed meal (treated and untreated) soyabean meal, coconut meal, brewers dried grain and field peas.

The density of AAT ranged from 6.4 to 8.1 g AAT/MJ ME, but only one treatment group exceeded 7.4 g AAT/MJ ME. There tended to be a linear response in milk production (kg ECM, kg protein) when AAT density increased within the range mentioned above. No optimum AAT level was found. The average regression coefficient for ECM production (kg/cow/day) on AAT density (g AAT/MJ ME) was 1.7, i.e. an increase in AAT density by one g AAT/MJ ME increased the ECM production by 1.7 kg. The corresponding figure for milk protein production (kg/cow/day) was 0.07.

The conclusion drawn from the experiments was that at least a level of 7.4 AAT/MJ ME was justified. The common way of presenting feed recommendations in Sweden is, however, the factorial way, i.e. giving recommendations for maintenance, milk production, growth, and growth of foetus. Recalculating the figures in this way and using the maintenance value of $0.507 * W^{0.75}$ (MJ ME/cow/day) for energy and $3.25 * W^{0.75}$ (g AAT/cow/day) for protein, and the prevalent recommendation of 5.0 MJ ME /kg ECM leads to a figure just below 40 g AAT /kg ECM for production levels within the range of the experiments. The actual energy levels in the experiments, however, exceeded 5.0 MJ ME (mean 5.4, range 5.1-5.7). Later investigations have also shown that the energy efficiency falls by 1.5% for every multiple of maintenance fed (Andresen, 1994). Taking this into consideration may

increase the level up to an extra 3 g AAT /kg ECM. Bearing in mind the many uncertainties in the system, 40 g AAT /kg ECM was considered to be a reasonable figure.

In all experiments PBV was always positive (up to +900 g). It was not possible to show any detrimental effect on health or fertility from this. It must, however, be of general interest to keep the PBV level down in order to lower the nitrogen load on the animal and in the end also on the environment. For this reason an upper limit of +300 g is suggested. A highest tolerated level of +600 g PBV is recommended. Experience from commercial farms warns from going below zero. PBV values below zero have in some cases been associated with decrease in milk production, which increased again after adjustment of the PBV level.

Before accepting AAT/PBV as the official system for evaluating protein for dairy cows a consequence analysis was performed (Magnusson et al., 1990). This analysis included calculations on feed costs, import, feed trade, environment etc.

From 1991, AAT/PBV is the official system for protein evaluation for dairy cows in Sweden (Spörndly & Bertilsson, 1992). The current Swedish recommendations for dairy cows were presented by Spörndly (1993) and shown in table 13.

Growing cattle

In Sweden, initial recalculation of data from production experiments gave promising support for the AAT/PBV system compared with digestible crude protein (DCP) in predicting the protein needs for growing cattle (Olsson, 1987; Olsson & Lindberg, 1985). In a more recent experiment, the interrelationship between AAT and PBV was more critically considered (Olsson et al., 1991). These data, together with information available mainly

Table 13. Swedish AAT and PBV recommendations for dairy cows

	Maintenance	3.25 x $W^{0.75}$	g AAT/day
	Milk production	40	g AAT/kg ECM
	Growth		
	1 st calvers	52	AAT/0.25 kgweight gain
	older cows	250	g AAT/kg weight gain
	Weight loss	-185	g AAT/kg weight loss
	Pregnancy (600 lw)		
	7th month	59	g AAT/cow/day
	8th month	98	g AAT/cow/day
	9th month	168	g AAT/cow/day
PBV:			
	Ideal value	0	g PBV/cow/day
	Recommended interval	0±300	g PBV/cow/day

Table 14. Swedish recommendations for goats (Ciszuk, 1992)

	AAT, g
Maintenance per day	
Generally	2.5 g/kg $W^{0.75}$
Live weight, kg	
50	47
60	54
For pregnancy, per day	
4th month	20
5th month	40
For milk production, per kg ECM	50
PBV- interval, g/animal/day:	0- + 30

Table 15. Swedish rekommendations for sheep. (Havrevoll et al., 1992

	AAT,g
Maintenance, per day	
40	42
50	50
60	57
70	64
80	71
90	77
100	83
Extra for pregnancy, per day	
Ewes with an average litter size <2	
6 weeks before parturition	20
2 weeks before parturition	60
Ewes with an average litter size >2	
6 weeks before parturition	30
2 weeks before parturition	105
Extra for milk production, per day	
At average lamb growth	
Litter size 1 lamb	120
Litter size 2-3 lambs	170
litte size 3-4 lambs	210
Suckler lambs in intensive indoor rearing	
Litter size 1-2 lambs	190
Litter size 3-4 lambs	250
Extrato rams during breeding season, per day	120
Flushing	20 -30
Recommended PBV-interval, g/animal/day	

from more recent Danish experiments (Andersen & Foldager, 1988; Andersen et al., 1994), reveal obvious difficulties in establishing recommendations for the supply of AAT and PBV that could cover the wide range of diets used for growing cattle under practical feeding conditions. At present, the official recommendations for the protein supply to growing cattle in Sweden are still expressed in terms of DCP as the AAT/PBV system is not considered to be an advantage. However, many advisers express a strong wish that the requirements for growing cattle should be given in terms of the AAT/PBV system to make the recommendations conformable to those for the dairy cows.

Goats and sheep

The Swedish protein recommendations is shown for goats in table 14 and for sheep in table 15. They were presented by Spröndly (1993).

FINLAND:

The Finnish protein recommendations for dairy cows is shown in table 16.

Growing cattle

The AAT recommendations are according to the Frensh PDI requirements(INRA 1989). The PBV has to be 0 or above.

Goats and sheep:
No recommendations.

Table 16. Finnish AAT and BPV recommendations for dairy cows

Dairy cows:		
AAT:		
	Maintenance	3.25 g * weight in $kg^{0.75}$ per day
	Milk	45 g/kg ECM
	Gestation (INRA 1989):	
	7th month	75 g/day
	8th month	135 g/day
	9th month	205 g/day
	Live weight change (AFRC 1992):	
	gain	233 g/kg
	loss	138 g/kg
PBV:		
		0(-200) g/day

ICELAND

Cattle, sheep and goats:
No recommendations

IMPLEMENTATION OF THE AAT/PBV SYSTEM INTO PRACTICE

All the Nordic countries have agreed to substitute the previously used digestible crude protein system with the AAT-PBV system for protein evaluation for ruminants. Denmark introduced the system in 1989, Sweden in 1991 and Norway in 1993. Finland intends to introduce the system in 1995, and Iceland has not taken any descision on when to introduce the system.

The first years following the introduction of the new system has shown major changes in the feeding of ruminants. The preference and use of different feedstuffs in milk production has changed, for instance in Sweden more rapeseed products (treated), sugar by-products, maize gluten meal and wheat have been used, the use of oats and soyabean meal (untreated) decreased, and the protein level in the diet for dairy cows has been decreased, for instance in Denmark in the order og 5 - 10%. During the same period, however, there has been so many other changes that will affect the pattern of feeding, e.g. milk quotas and increased genetic potential of the cows, price relations of protein supplements and the payment for milk and milk components. This makes it difficult to separate those effects from the new evaluation of protein.

In general, it has been observed that the potential of decreasing the protein allocation is greater than the possibilities of increasing the milk yield or the weight gain, by using the AAT/PBV system instead of the digestible crude protein system.

AAT_X ON AN INDIVIDUAL AMINO ACID BASIS

The success of introducing modern protein evaluation systems has led to an increased interest in individual amino acids, especially lysine and methionine. The PDI system in France has recently been extended to also include calculations of supply and requirement for lysine and methionine (Rulquin et al., 1993). The background for this was production experiments where it was shown that in some diets either lysine or methionine or both were limiting milk protein production. The prediction of lysine and methionine absorption in the PDI system is based on amino acid analysis on the feeds and the assumption that degradability and digestibility of individual amino acids are the same as found for total protein. In Sweden the AAT system has also been extended to include calculations of AAT_{Lys} and AAT_{Met} (Spörndly, 1993a). The calculations are based on the same principles as outlined in the AAT system where the individual amino acid is exchanged for total protein.

Both field studies and station experiments in Sweden have shown, however, that the use of the AAT-system to predict individual amino acids does not lead to any benefits (Gran et al., 1993). The reason for this may be that the prediction is too uncertain, but it may also be that the amino acids investigated did not limit milk production, at least not at the levels they were fed in the experiments. No effects of lysine absorbed in the small intestine(AAT_{Lys}), calculated on the basis of the AAT system, were seen when exceeding 8.4 g AAT_{Lys} per kg DM in the

concentrate or 4 g AAT_{Lys} per kg energy corrected milk (ECM) produced (Gran et al. 1993).

DISCUSSION AND CONCLUSION

In all the Nordic countries, experiments are carried out to get more knowledge about the AAT-PBV value of the many different feeds and the requirements of the different categories of ruminants. At the same time experiments are carried out to evaluate and improve the system. This leads to a continous development and improvement of the system, but also gives some problems. When the amount of knowledge is not the same when the first and the latest country introduce the system, then it requires that the latest country do not take all the knowledge into account or the country to introduce the system first has to change the system in order to keep a uniform system in all the Nordic countries. To change the system is also a problem, as changed AAT-PBV values of the feeds require that the earlier production experiments has to be recalculated to correct the recommendations. These problems leeds to a great demand for monitoring the development in the different countries and may look as if we at some times are going in different directions, but it rather reflects that there is a continous development in different areas and that new knowledge are incorporated in the system in the different countries when convenient.

There has been no change in the basic framework of the system. AAT and PBV are still considered to be the most appropiate expressions for the protein value of feeds for ruminants. The elements in the nitrogen metabolism that has to be quantified to be able to calculate the AAT and PBV values are also the same. Changes, and thereby differences between the countries at a certain time is at the moment: 1). In the technique used for measuring protein degradability in the rumen, where correction for particle loss from the nylon bag and correction for microbial contamination in the bag, not has been uniformly adjusted for. The passage rate used to calculate the degradability is also under discussion, 2) The correctness of relating the microbial syntesis only to the digested carbohydrates and not considering the potential microbial synthesis on basis of the energy in the degraded protein, and the method to predict digested carbohydrates, is also under discussion, 3) The factor of 0.82 for intestinal digestibility of undegraded protein is also under discussion and change. It is agreed that it is not a constant figure, but an appropriate technique for all feeds has not been developed yet, and therefore there are differences concering this factor at the moment in the different countries.

The recommendations for the amount of AAT and PBV to be fed to the animals will always differ as the conditions for the production and especially the prices of protein supplements will vary between countries. Moreover, the energy evaluation systems are different and the feeding systems are different. The presented requirements used in the different countries can be compared with the French recommendations, as there are certain consensus between the French PDI value and the Nordic AAT value and the PBV value can be calculated from the French system.

Verité & Geay (1987) summarize the French production experiments with dairy cows and recommend a requirement of 50 g PDI per kg 4% FCM except in the first 2 to 3 months of lactation where the mobilization can meet the protein requirement for approximately 200 kg 4% FCM which means that the requirement

in this period is only 45 g PDI per kg 4% FCM. The requirement for maintenance is given as 3.25 g PDI per kg metabolic body weight (Verité et al., 1987). The PBV recommendation given by Verité & Geay (1987) when recalculated to our system is approximately -10 g PBV/SFU in the beginning of the lactation, and -15 g PBV/SFU in mid lactation. Verité et al. (1987) tolerate down to -40 g PBV/SFU for dry cows.

Verité et al. (1987) specify the amino acid requirement for growing animals as 250 to 350 g PDI per kg weight gain plus the requirement for maintenance. This interval in PDI requirement is a result of both different content of protein in the gain and decreasing utilization of absorbed amino acids with age. Recalculating values from the French system (Verité et al. 1987) to PBV values show that fast growing animals can only tolerate down to -20 g PBV/SFU.

It is obvious that the results concerning the AAT-PBV requirements for young growing animals are not in good agreement among the different authors. The AAT requirement could not be established in the Danish and the Swedish experiments (Andersen & Foldager, 1988; Andersen et al., 1994; Olsson & Lindberg, 1985; Olsson, 1987; Olsson et al., 1991). The calculated PBV in rations using the present requirements for digestible crude protein in Denmark will in some cases be as low as -70 g per SFU, whereas Verité et al. (1987) recommend that PBV should not be below -20 g per SFU, and Olsson (1987) assume that PBV must not be less than -2 g/MJ. The reasons for these differences may be several. One reason could be that sufficient attention has not yet been given to the necessity of evaluating the requirement for AAT and PBV simultaneously, which is of importance as the level of one of the parameters may influence the level required for the other and of major importance for these animals where the extent of recycling is of significance. Also for other categories of animals, it is of importance to evaluate the AAT and PBV requirements together. When the protein requirements for dairy cows in late lactation, for suckling cows and other ruminants with a low protein requirement compared to their energy requirement are going to be established in the future, this joint evaluation of AAT and PBV may prove to be of major importance. It should also be stressed that in many situations with low growth rates or milk production PBV rather than AAT may be the limiting factor for optimal feed utilization and production. In such situations an establishment of separate AAT requirements cannot be made in production experiments. Future experiments should focus more on the PBV requirements and the qualitative N requirements of the rumen microorganisms.

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- The issue number is given in parentheses after the volume number and only in cases where each issue of a particular volume begins on p. 1.
- A colon is used before page numbers in journal articles.
- The year of publication suffices where the volume number is missing.
- In references to a book, the name of the publisher and the place of publication are given after the title of the book. If more than one edition of a book has been published, the edition used must be indicated. The number of pages should be given.
- It is recommended not to abbreviate the titles of periodicals, but in cases where this has nevertheless been done, abbreviations should be in accordance with the World List of Scientific Periodicals and/or BUCOP British Union Catalogue of Periodicals.

ABBREVIATIONS

Use standard abbreviations where available, otherwise abbreviations given in the text should be explained at their first mention. Quantities and units of measurement shall be in accordance with «Systéme International d'Unites« (SI).

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Page proofs will be sent to the author for proofreading. They should be read immediately and returned to the journal's editorial office. Printer's mistakes should be marked with a blue pen and any possible changes made by the author against the manuscript in red. The second proof will be checked at the editorial office.

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